

# **The LLNL Quadrupole Array<sup>\*</sup>**

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## Abstract

Short sample field gradient and current, harmonics and forces have been calculated from a 2 and 3 dimensional model of a racetrack quadrupole array. The coil is a simple racetrack (Fig. 1,2) with rounded ends made of 23 turns of Rutherford cable. The 26 strand cable uses SSC outer strand with a 1.8:1 cu/sc ratio. The maximum field was located in the end, 6.02 T at  $J_{sc}=2055$  (A/mm<sup>2</sup>) corresponding to a short sample current of 6295 A and a maximum gradient of  $G_{ss}=47.0$  T/m. The overall current density (over cable and insulation) is 530 (A/mm<sup>2</sup>). The field quality in the straight section at a radius of 4.8 cm is  $b6=-5$  units and  $b10=-19$  units. The maximum stored energy in a single quad is 110.7 (kJ/m).

Reducing the field in the end (adding a spacer) to the same level as the straight section will raise the short sample gradient from 47.0 (T/m) to 48.9 (T/m). With no spacer in the end the field quality especially that of the dodecapole can be cancelled (in the integral sense) against an offset in the magnet straight section.

m	G (T/m), @6295 A	b6 (units)	b10 (units)	b14 (units)	b18 (units)
Biot_Savart 2D	-47.017	-5.17	-19.21	-0.585	0.047
POISSON 2D	-46.709	-4.87	-19.34	-0.623	0.062
Center of 3D	-47.01	-5.38	-19.3	-	-
Average over magnet	-47.01	-75.6	-17.44	-0.409	-

Table 1 Harmonic at a radius of R=4.8 cm, calculated from a 3x3 array using Biot-Savart and POISSON assuming an infinite array.

Integrated harmonics over the magnets (page 6) suggest that a large fraction of negative b6 is coming from the ends. Displacing the coil 0.3 mm towards the midplane (along a 45 degree line) will introduce a positive b6 that will reduce its integrated value significantly. The integrated b10 will also be reduced somewhat.

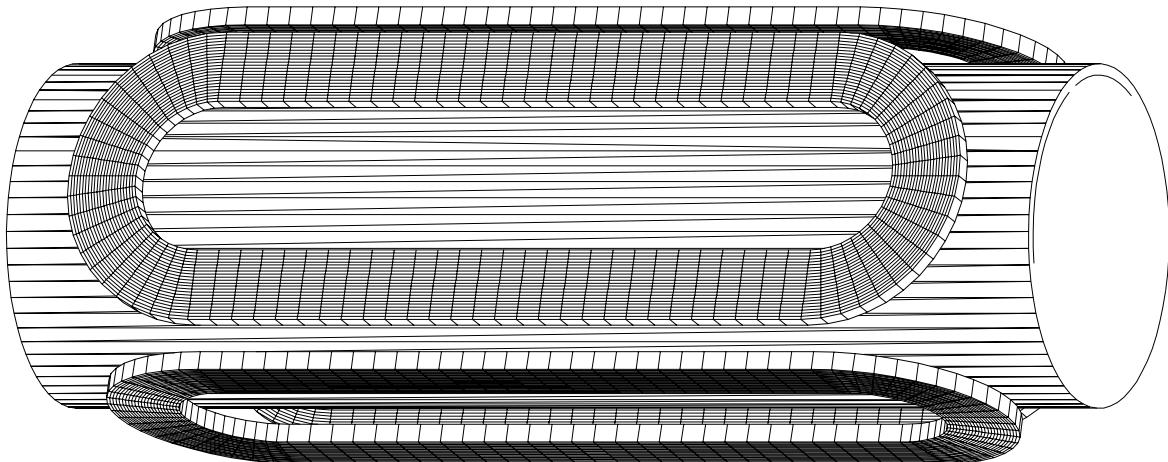


Figure 1 View of a single magnet (AutoCad).

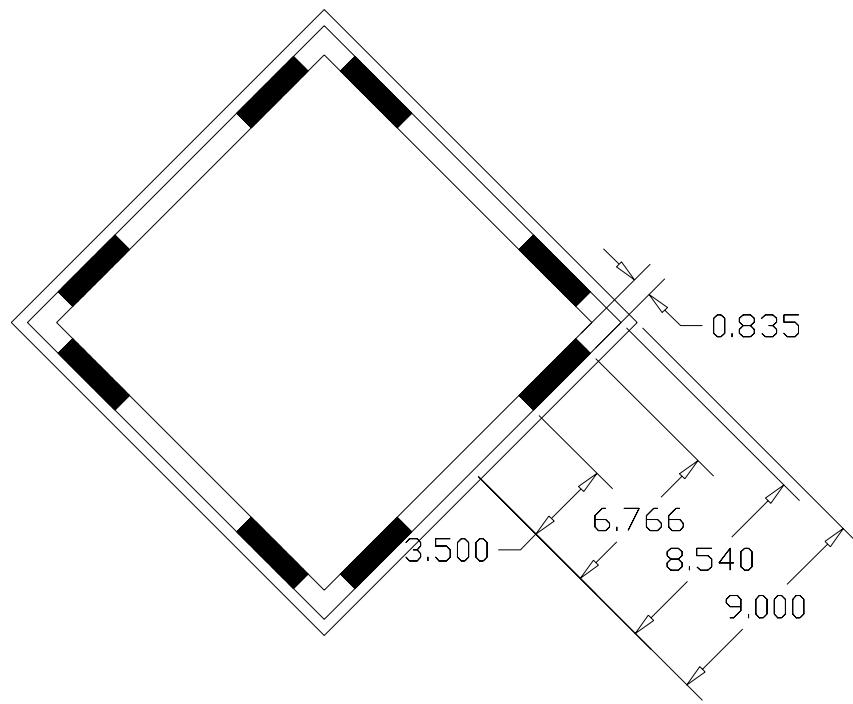


Figure 2 A unit cell.

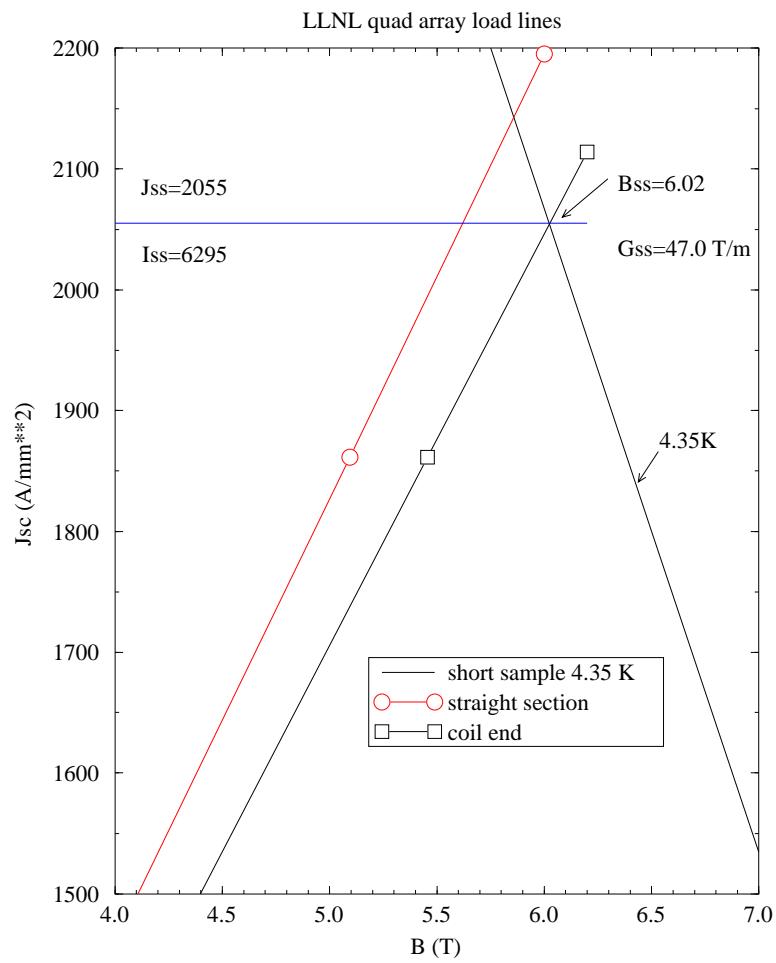


Figure 3 Short sample curve and two load lines — one based on the straight section (top) and the other based on the end field (bottom).

LLNL 2x13 strand cable for Quad Array

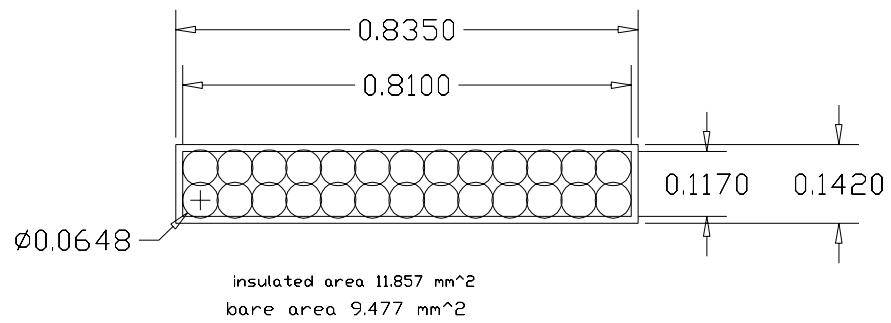
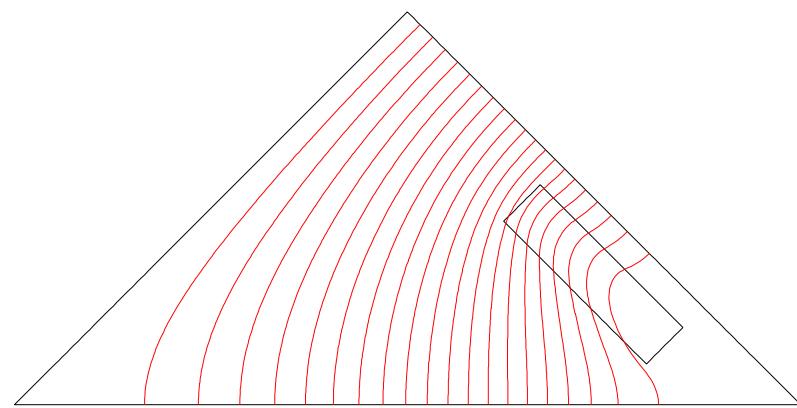


Figure 4 A 26 strand cable using SSC outer conductor.

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LLNL Quad array 5/28/99 CYCLE = 1700

Figure 5 Flux plot

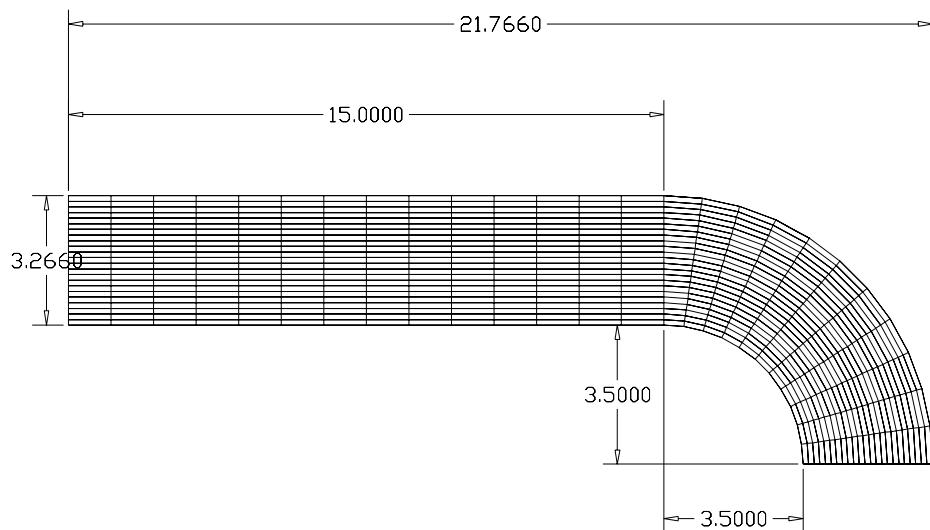


Figure 6 Overall coil length and end view.

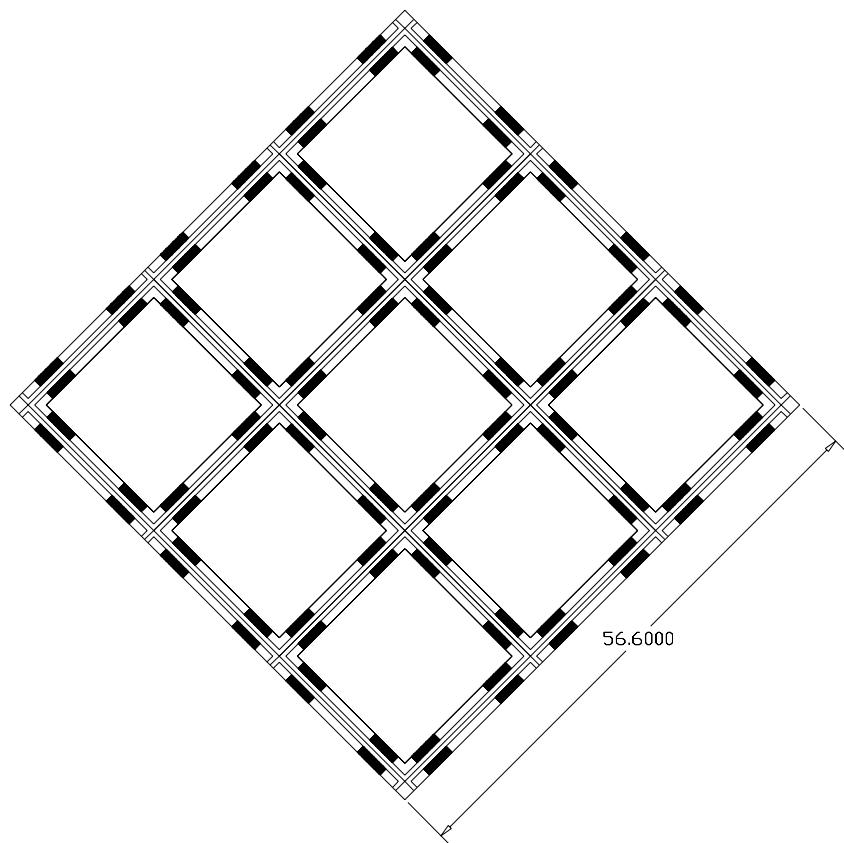


Figure 7 An assembly of 12 elementary cells and edge coils.

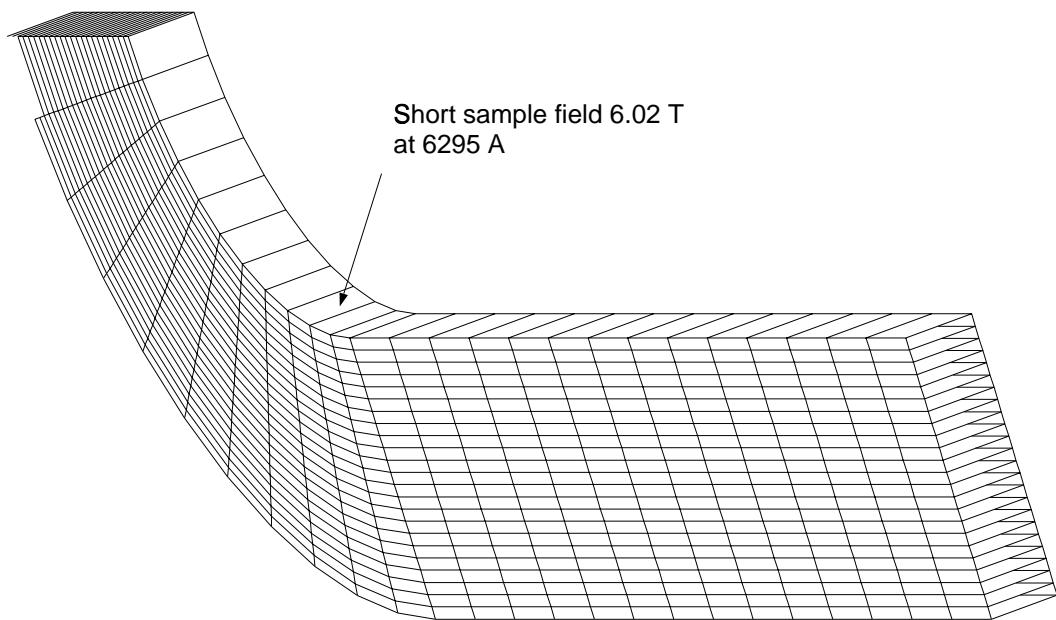


Figure 8 Location of maximum field at the end.

## Forces

Lorentz forces were calculated using Biot-Savart, Poisson and Tosca. The total transverse force along an edge of a 3x3 array is 1244 (kN/m) and the total axial force (end) is 944 (kN). Local forces within the array are also shown. All forces are at 5700 A and should be multiplied by  $\left(\frac{6295}{5700}\right)^2 = 1.22$  for short sample performance.

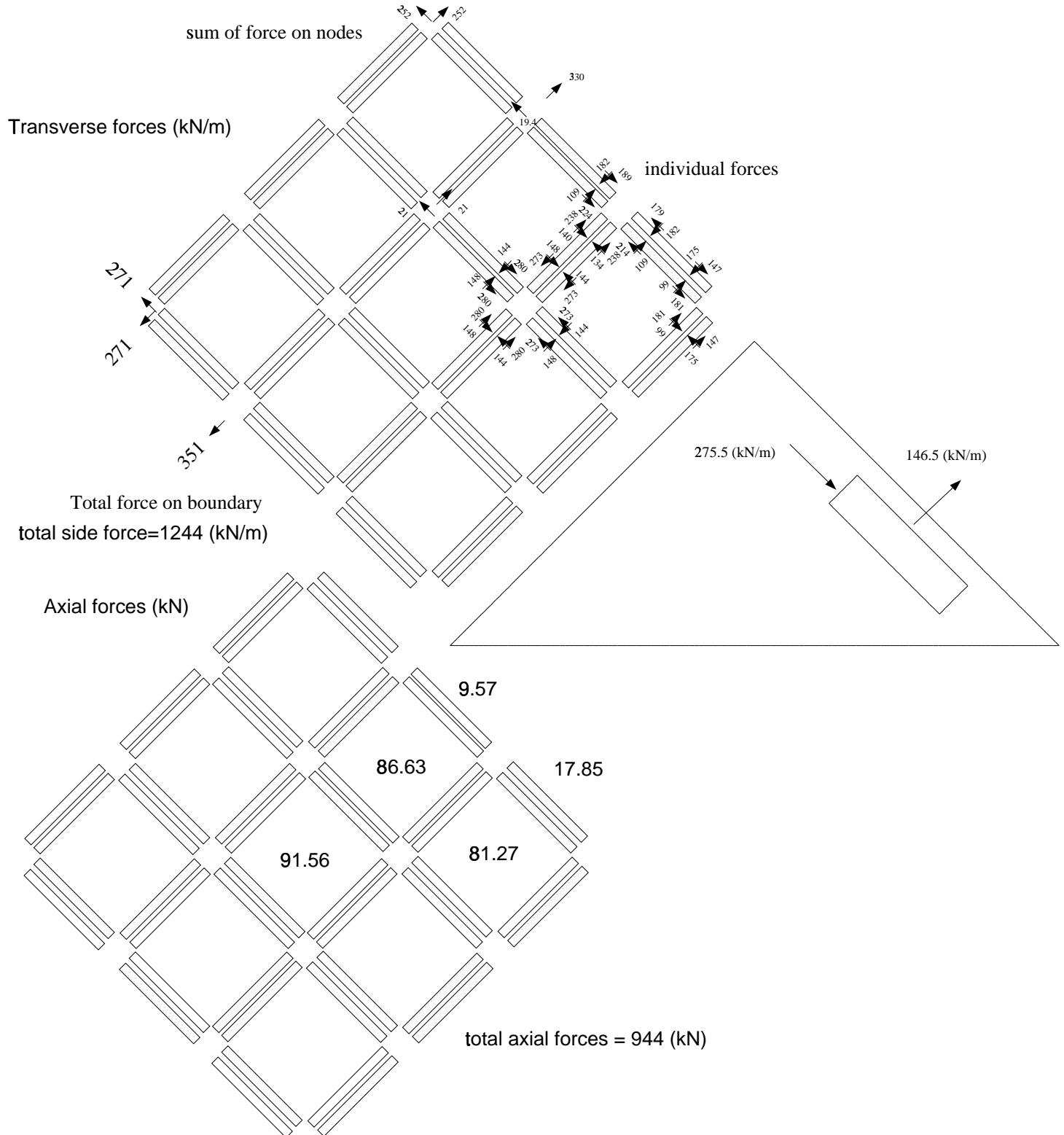


Figure 9 Lorentz forces at 5700 A

### 3D harmonics

The local and integrated harmonics are plotted in the next two figures. Based on integral values the magnetic length is 39.17 cm at 47.01 T/m = 9.20688 T (the physical length of the coil is 43.52 cm). Based on the integrated values over the physical length :

$$|B| = G_0 \rho \left[ 1 - 75.6 * 10^{-4} \left( \frac{r}{4.8} \right)^4 - 17.44 * 10^{-4} \left( \frac{r}{4.8} \right)^8 - 0.409 * 10^{-4} \left( \frac{r}{4.8} \right)^{12} \dots \right]$$

$G_0 = -47.0098 \text{ T/m}$  ,  $\rho$  in (m)

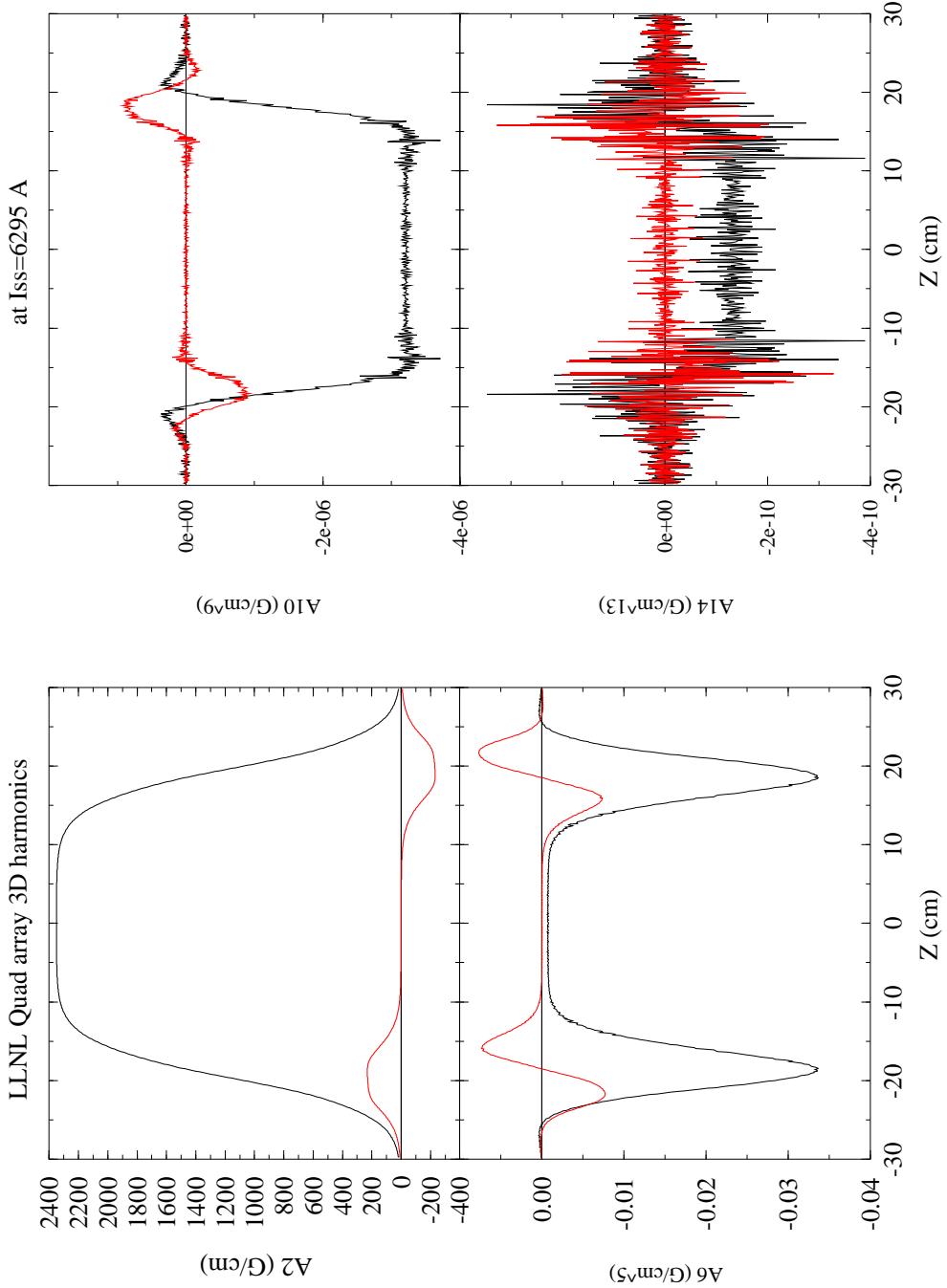


Figure 10 Local harmonics and pseudo harmonics over the entire magnet.

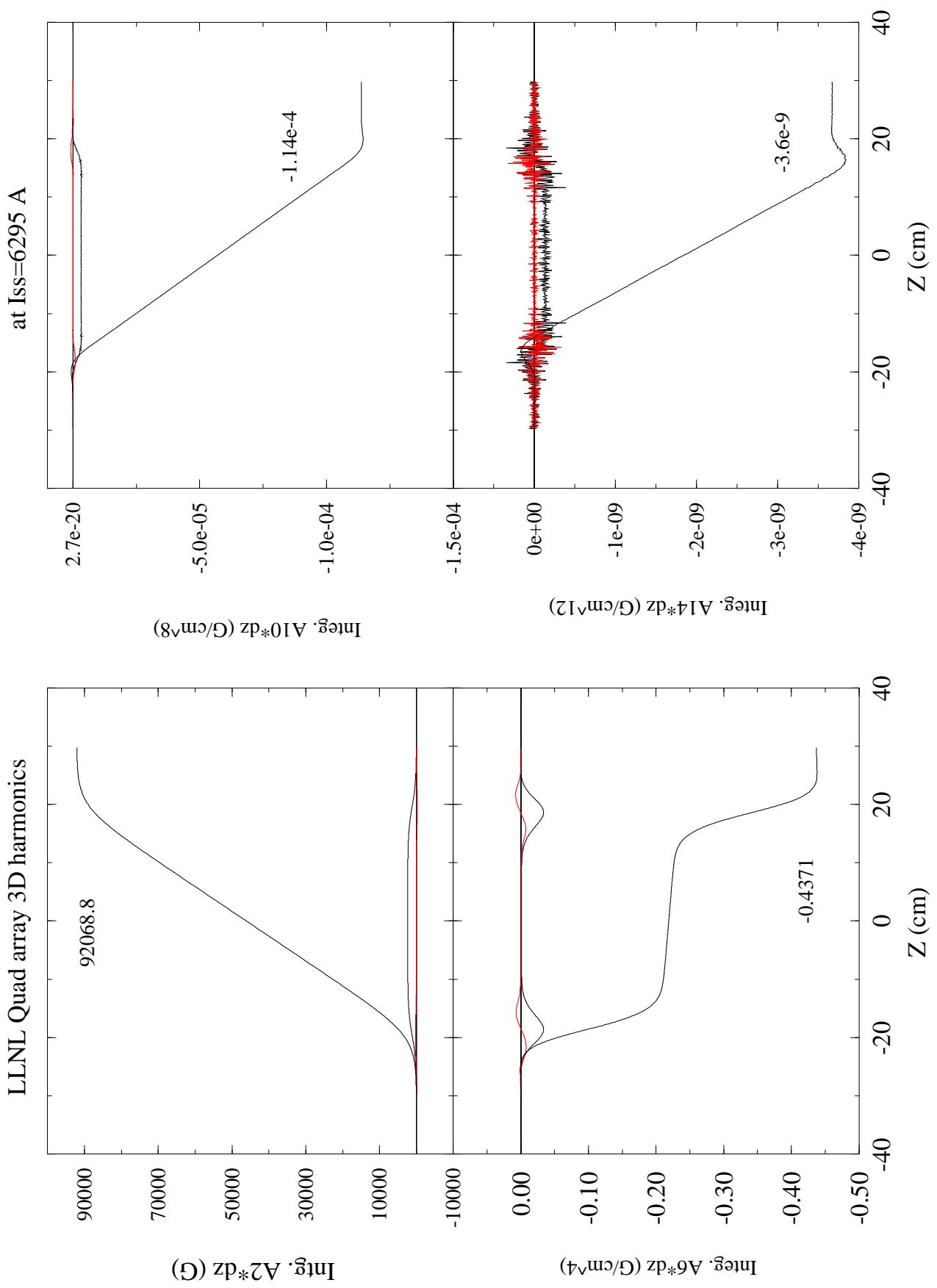


Figure 11 Integrated harmonics over the entire magnet.

## **Tosca**

The Tosca model used in the field calculations (Fig. 11,12).

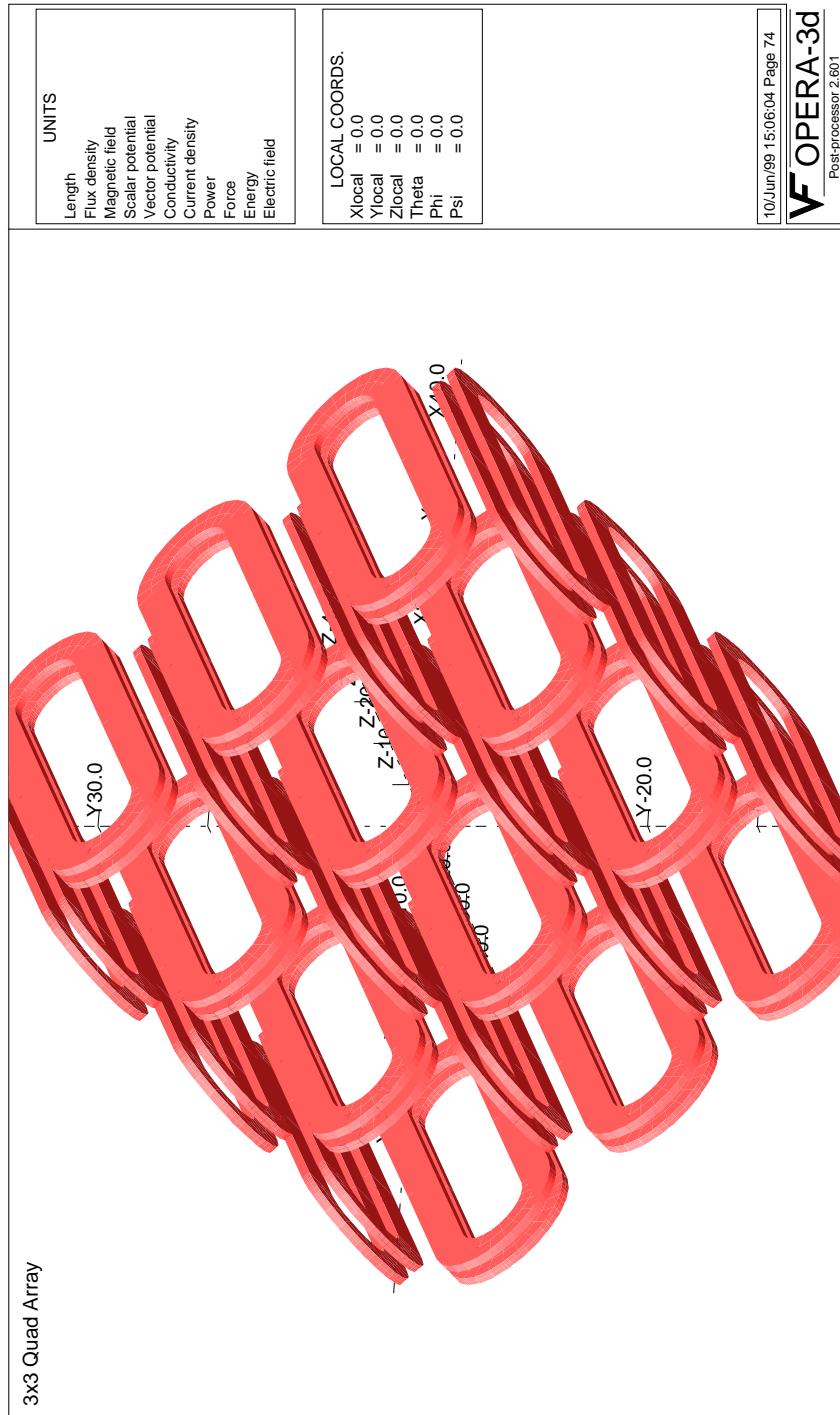


Figure 12 View of a 3x3 model used in Tosca calculations.

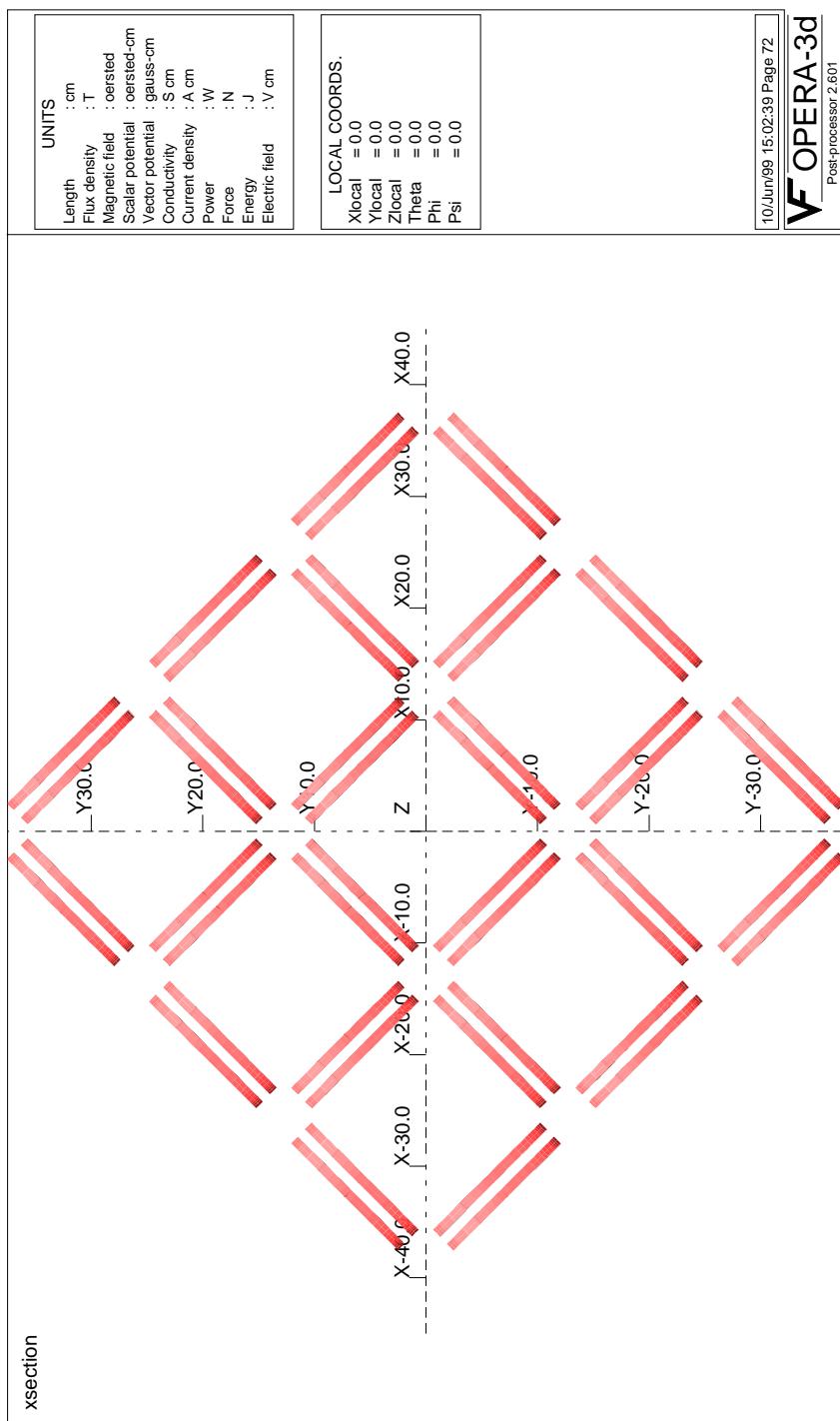


Figure 13 End view of the Tosca model.